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Quantum dots in micropillar cavities for scalable photonic applications

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Abstract: Scalable quantum photonic applications require wavelength reproducibility and high quality of the emitted photons. To address these issues, we investigate strain-tuning of self-assembled semiconductor quantum dots embedded into micropillar cavities. © 2019 The Author(s)

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1. Introduction

Self-assembled semiconductor quantum dots are good sources of indistinguishable single photons [1] and entangled photon pairs [2]. Furthermore, the ground state spin of a trapped electron or hole can be used as a spin qubit [3]. Besides relatively short spin coherence times [4], one of the main drawbacks of quantum dots is the inhomogeneous distribution of the emission wavelength, due to the randomness of the growth process. For any kind of quantum gate with photons, the emitted photons have to be indistinguishable in all degrees of freedom, which includes their central emission wavelength. Experiments that include more than one quantum dot are subject to low device yield and are not scalable, because the aforementioned inhomogeneous wavelength distribution requires cherry picking of two (or more) quantum dots. This problem of random wavelengths has been recently solved by applying strain from various directions [5] on a device that did not include any kind of nanocavity. However, the highest quality emission in respect to indistinguishability of photons has been achieved when quantum dots were embedded into cavities [6].

Here, we show that quantum dots in micropillar cavities can also be tuned by strain, which enables their use in scalable applications. For example the scheme presented in Refs. [7, 8], which is a first building block for a quantum repeater, could be upscaled to more than two, because the emitter is in a cavity, which makes it more efficient and even more importantly, it can be tuned.

2. Results

We fabricated an array of micropillars on a medium-density InAs quantum dot sample embedded into a λ -distributed Bragg reflector cavity, composed of 15 top and 25 bottom pairs of alternating AlAs and GaAs. The sample was thinned down to approximately 30 μm and placed on a $[\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3]_{0.72} - [\text{PbTiO}_3]_{0.28}$ (PMN-PT) piezoelectric substrate. The substrate was not micromachined for full control over the strain tensor as in Ref. [5], but instead a slab of piezoelectric material (as in Ref. [9]) was used. The micropillars were not fully etched through, but the etch stopped just below the cavity layer to ensure strain transfer into the quantum dots. By applying voltage to the piezoelectric substrate, the quantum dot emission can be tuned for about 0.5 nm (0.75 meV), see Fig. 1. The cavity resonance is not influenced by the applied voltage, as also visible in Fig. 1. The quality factors of the micropillar cavities is reduced compared to fully etched cavities. On some devices we could measure a Purcell factor of $F_P = 4.4 \pm 0.7$.

The next step towards an useful implementation for quantum communication is to investigate the indistinguishability of distant sources, where either only one, or alternatively, also both sources are placed on piezoelectric substrates. As mentioned above, this will be a crucial step for any kind of gate and will also determine if the device can be used for some even more advanced experiments like the ones presented by Ref. [7, 8].

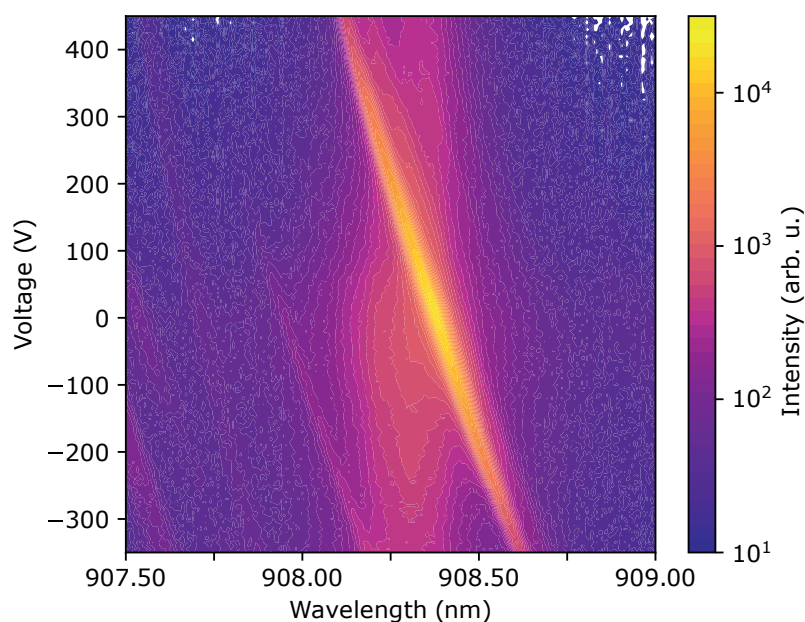


Fig. 1. Emission of a quantum dot embedded in a micropillar cavity on a piezoelectric substrate for different piezo voltages. The emission is plotted in logarithmic scale to make the faint cavity mode visible (broad feature at 908.3 nm). The cavity mode is not influenced by the applied strain and stays constant, while the quantum dot emission can be tuned in and out of resonance.

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